SEISMIC EVALUATION AND RETROFITTING PROPOSAL OF REINFORCED CONCRETE SCHOOL BUILDING IN EL SALVADOR

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ABSTRACT

The urgency for an official seismic evaluation guideline for buildings in El Salvador is driven by the historical damage from earthquakes, which have caused significant economic and human losses. Currently, local engineers depend on various international standards due to the absence of national regulations. In response, the HOKYO Project aims to develop manuals and guides for seismic evaluation and retrofitting of buildings in the San Salvador metropolitan area. This study focuses on a detailed seismic evaluation (DSE) and retrofitting of a reinforced concrete school building in El Salvador. The DSE method integrates the seismic index method from Japanese standards with non-linear analysis criteria from American standards, providing a comprehensive approach to assess and enhance the seismic performance of buildings. The research evaluates the building's seismic performance both as a bare frame and with the inclusion of four different retrofitting techniques, such as reinforced concrete walls, steel bracing, ferrocement lamination, and reinforced concrete block walls. The findings aim to establish an optimal seismic evaluation and retrofitting method suitable for typical school buildings in El Salvador, addressing the need for improved safety in educational infrastructure built before the current seismic design standards.

Keywords: Retrofitting, detailed seismic evaluation method, reinforced concrete building.

1. INTRODUCTION

El Salvador is in a tectonically active region, which makes it susceptible to intense seismic activity. The buildings in San Salvador metropolitan area are diverse structural systems, commonly reinforced concrete (RC) frame systems, designed to withstand the seismic activity In the region, many of these structures are public buildings, such as schools, designed and built before the current technical standard for earthquake design. El Salvador's technical standard for earthquake design and construction (NTDS-94) establishes the minimum requirements for new buildings to guarantee their resistance to seismic events. These standards cover site evaluation, structural design, material selection, and construction. However, this standard does not include specific considerations for retrofitting existing structures and primarily focuses on the construction of new buildings that comply with the established seismic safety standards. The Detail Seismic Evaluation (DSE) method combines the seismic index method procedure with the static non-linear analysis criteria established in American standards such as (ASCE41-13), and it extends the analysis to all structural members of the building. This approach intends a better integration of Japanese methodology process with American standards. Research in recent years has used DSE in buildings considering only bare frames or the incorporation of a single retrofitting technique giving very reliable results; however, DSE has not been used with more than one seismic retrofitting technique. Therefore, the purpose of this research is: evaluate the seismic performance of a typical RC school building according to the Detail Seismic Evaluation (DSE) method, in one first step

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considering the building as a bared-frame structure and then evaluate the seismic performance of the building with the incorporation of retrofitting techniques such as reinforced concrete wall, steel bracing, ferrocement lamination, and reinforced concrete block wall.

2. DATA

A representative school building with a typical typology was selected for this study. It was two-storied and constructed in 1966; its structural system comprised RC frames with nonstructural brick masonry walls. Basic building information is summarized in Table 1.

Table 1. Basic building information.

Item	Information/Data
Use	School building
Structural type	Reinforced concrete frame
Number of stories	2
Usage and importance factor	Cat I=1.5
Soil type	S3
Total seismic weight	4,385.63 kN
Construction year	1966
Total height	7.0m
Concrete strength	17.6 MPa
Expected yielding strength	302 MPa

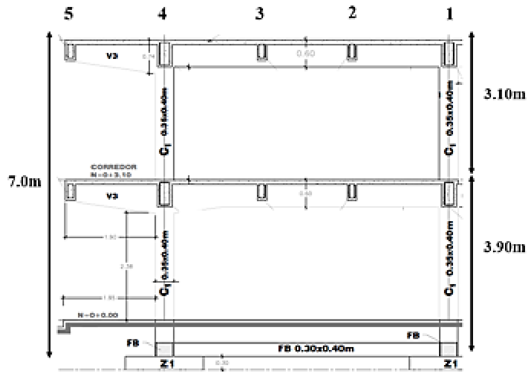


Figure 1. Elevation view structural element distribution

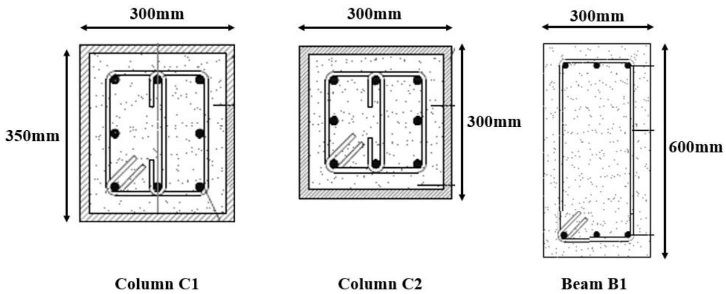


Figure 2. Principal's elements cross-sections.

3. METHODOLOGY

The methodology employed in this study adheres to the seismic evaluation procedure outlined in the JBDPA (2001). The process begins with selecting the target building, followed by calculating the seismic demand index (I_{S0}). For this calculation, we considered the spectral acceleration for the design earthquake derived from the NTDS-94 standards. The seismic evaluation of the bare frame building was conducted using software (ETABS ver 20.3) to perform a pushover analysis. The output data obtained from this analysis allowed for the calculation of the strength index (C) and the ductility index (F), as specified in the Detail Seismic Evaluation (DSE) method. The subsequent step involved comparing the seismic index (I_S) with the seismic demand index (I_{S0}), where the latter was found to be higher. As a result, seismic retrofitting was necessary. Steel bracing was utilized in the longitudinal X direction, while in the transverse Y direction, the techniques applied included RC walls, ferrocement lamination masonry walls, and concrete block walls.

3.1. Seismic evaluation of RC building using DSE method

According to this method, the collapse process of structural elements in the nonlinear region when a building is subjected to a seismic force can be obtained through a pushover analysis. Then, the strength index (C) and ductility index (F) for global building can be obtained through the spectral acceleration - spectral displacement of an (SDOF) curve. However, since the global capacity curve is insufficient to know the seismic performance of each story, it is necessary to assess the shear force-displacement relationship and calculate the corresponding indices through these curves. Depending on the type of failure mechanism, the C and F indices will be calculated according to the equations (1)-(3). Finally, the I_S index is calculated using Eq. (4).

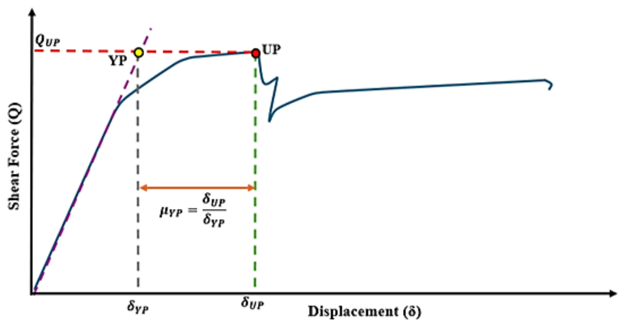


Figure 3. Evaluation of C index and F index at shear force-displacement curve, flexural failure mechanism.

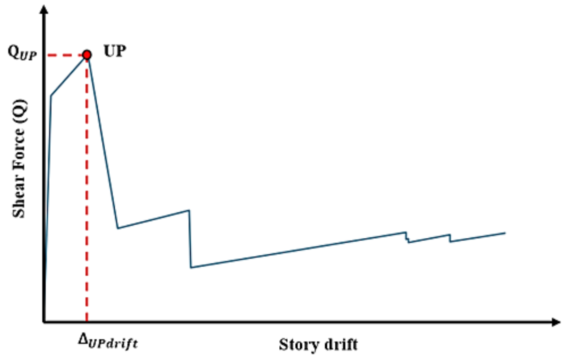


Figure 4. Evaluation of C index and F index at shear force-displacement curve, brittle failure mechanism

$$F = \mu_{UP} = \frac{\delta_{UP}}{\delta_{YP}} \tag{1}$$

$$C = C_{UP} = \frac{Q_{UP}}{\Sigma W_i} \tag{2}$$

$$F \approx \Delta_{UPdrift} \rightarrow (Brittle\ failure) \tag{3}$$

$$I_S = E_O.S_D.T = (\emptyset.C.F).S_D.T \tag{4}$$

3.2. Incorporation of retrofitting techniques

Four retrofitting techniques were considered and modeled for this study: steel bracing, RC wall, reinforced concrete block wall, and ferrocement lamination wall. The calibration of the properties of plastic hinges is based on theoretical and experimental fundamentals.

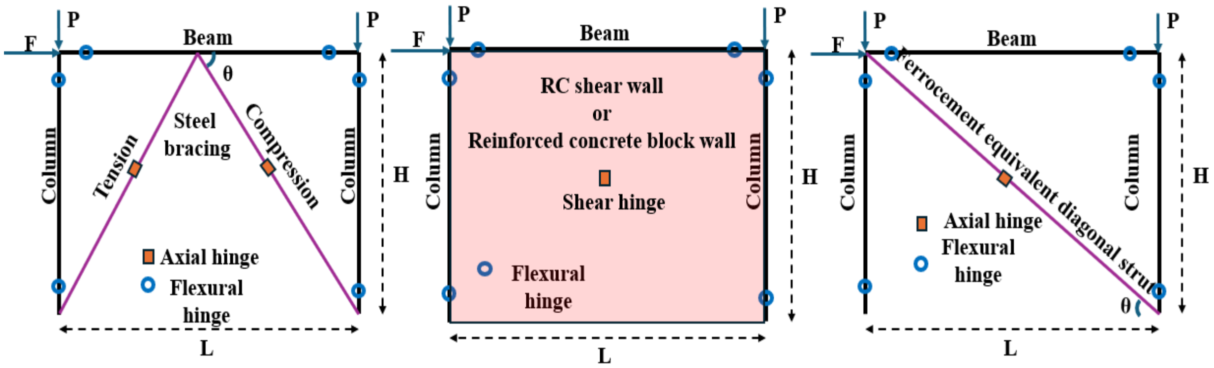


Figure 5. Concentric steel bracing, RC/Reinforced concrete block shear wall and Ferrocement lamination wall idealized model

4. RESULTS AND DISCUSSION

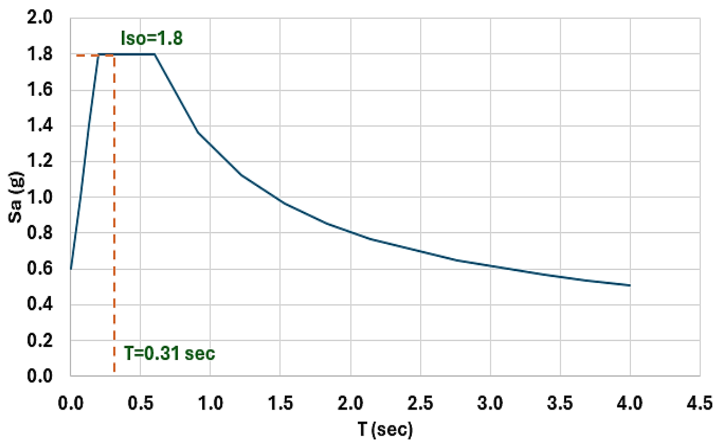
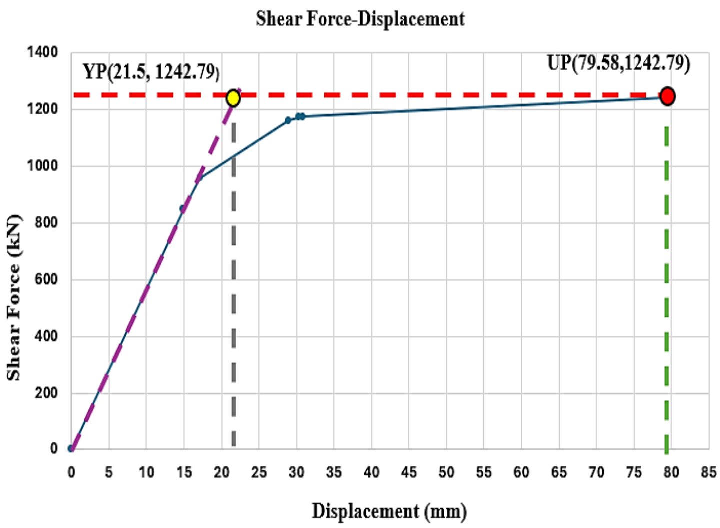


Figure 6. Elastic design acceleration response spectrum and demand index (I_{S0})

The demand index (I_{S0}) was calculated considering the spectral acceleration for the design earthquake derived from the NTDS-94 using Eq. (5)

$$I_{SO} = C_S . R \quad (5)$$

Where C_S indicate the seismic coefficient, and it represents the normalized acceleration response spectrum R is the response modification factor associated with the type of structural system.



As an example of calculation, the procedure for the first level in direction X is shown. The F and C indices were calculated following Eq (1) and Eq (2), however the F index was calibrated according to the results of the experiments of the HOKYO project where the construction processes and the quality of the national materials were considered.

$F = 3.70 \rightarrow 2.0$ (HOKYO project experimental data)

$C = 0.28$

Figure 7. Shear force vs displacement curve 1st story, X direction

Following the procedure described above, the seismic index *Is* was calculated for each story in both directions, and the results are shown in Figure 8. From the results, it can be observed that the existing building requires retrofitting.

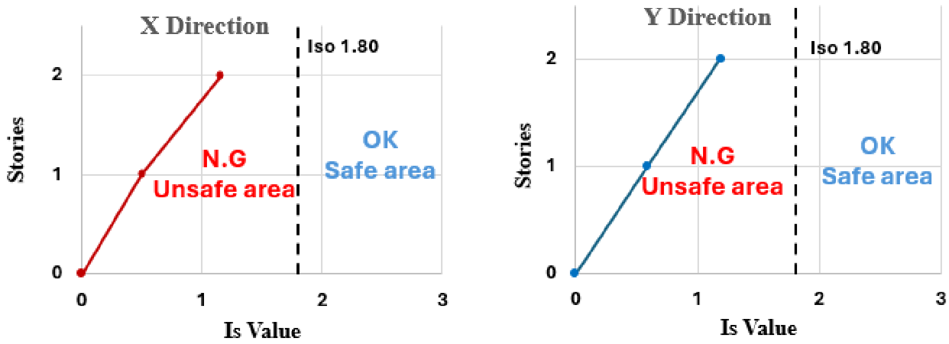


Figure 8. Seismic evaluation results in X and Y direction, both stories

For retrofitting proposal four techniques were considered as follow: Steel bracing was utilized in the longitudinal X direction, while in the transverse Y direction, the techniques applied included RC walls, ferrocement lamination masonry walls, and concrete block walls.

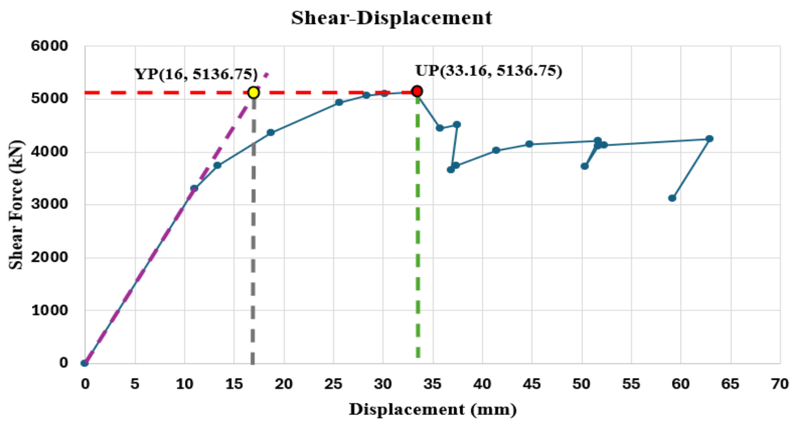
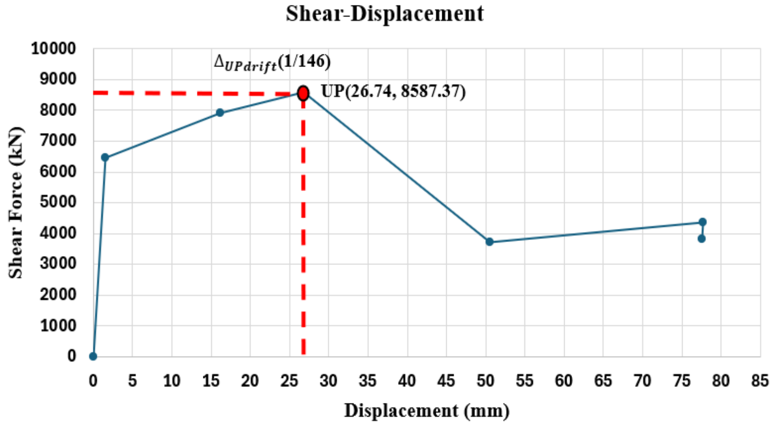


Figure 9. Shear force vs displacement curve 1st story, X direction retrofitting

As an example of calculation procedure for the first level in direction X for retrofitting condition is shown. The *F* and *C* indices were calculated following Eq (1) and Eq (2)

$$F = 2.0$$

$$C = 1.09$$



As an example of calculation, the procedure for the first level in direction Y is shown. The *F* and *C* indices were calculated following Eq (1) and Eq (3), the F index was calculated and calibrated considering the story drift limit and HOKYO project experimental data.

$F = 1.30$ (HOKYO project experimental data)

$$C = 1.82$$

Figure 10. Shear force vs displacement curve 1st story, Y direction

retrofitting

The seismic index *Is* was calculated for each story in both directions after incorporation of the retrofitting techniques, and the results are shown in Figure 11. From the results, it can be observed that retrofitting proposal was succeed.

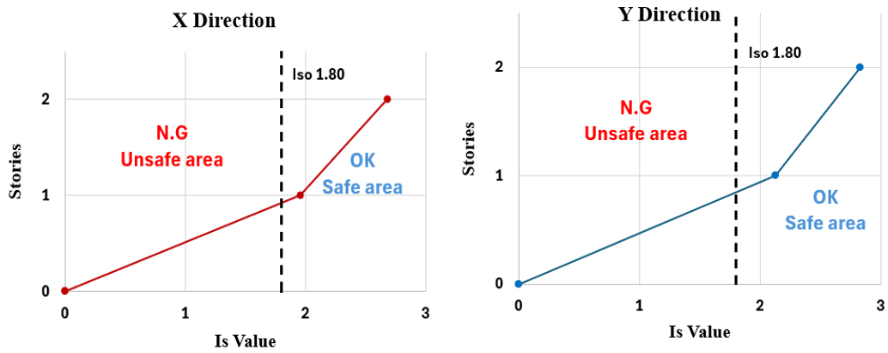


Figure 11. Seismic evaluation results in X and Y direction, both stories retrofitting.

5. CONCLUSIONS

From the results of this research, it can be concluded that seismic evaluation using the DSE method is feasible for low and medium-rise reinforced concrete buildings and produces excellent results. Furthermore, in order to effectively use the DSE method, it is essential to create simplified numerical models. These models must be supported by both theoretical principles and experimental validation. Finally, the use of steel bracing, RC wall, reinforced concrete block walls, and ferrocement lamination proved to be effective methods for improving the building's seismic capacity for this type of building.

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